CHAPTER 16

SOILS: SURVEYING AND EXPLORATION/CLASSIFICATION/FIELD IDENTIFICATION

In this chapter you will be introduced to the topics of geological and pedological surveys and will learn about various methods used for this type of surveying. Additionally, you will further your knowledge of soils exploration and you will learn how to classify soils based on their textural and plasticity-compressibility characteristics using the Unified Soils Classification System. Finally, you will learn various field tests that are useful for expedient soil classification.

Much of the discussion in this chapter assumes that you are by now knowledgeable of the physical properties of soils and that you are experienced with laboratory testing procedures, such as mechanical analysis and Atterberg limits, that are necessary for accurate identification and classification of soils. Should it be necessary, you may find it helpful to review chapter 15 of the EA3 TRAMAN and chapter 13 in Part 1 of this TRAMAN before beginning your study of this chapter.

SURVEY SUPPORT FOR GEOLOGY AND PEDOLOGY

In this section you will be provided a brief familiarization with the topics of geological and pedological surveying and mapping. Although these topics could have been included in a separate discussion of topographic surveying, they have been included in this chapter since both are related to soil exploration and investigation.

GEOLOGICAL SURVEYS

In essence, surveys in support of geology are topographic surveys; however, you must be aware of the other specialized data that may be included as required by the geologist or the soil engineer when you are collecting data for engineering studies for naval construction projects.

The end product of most topographic surveys is a topographic map. In geology or other related sciences, the topographic survey is the first part of a series of interrelated surveys. The end product is a map containing not only topographical information but also other specialized data keyed to it. In geologic surveys, a geologist makes systematic observations of the physical characteristics, distribution, geologic age, and structure of the rocks as well as the groundwater and mineral resources that the rocks contain. These observations are expressed in finished form as geologic maps and texts. The objective of the geological survey is to portray, in plan or in cross section, geological data required for subsequent constructions or for other uses.

Pure geological data has little direct application to naval problems; however, if the field information is interpreted into specialized lines, it is of considerable use in Naval Construction Force (NCF) planning and operations. NCF requirements may necessitate regional geological study and mapping, surveys of more limited areas, or development of detailed geological data at a construction site.

Methods of Geological Surveying

Most geological data is gathered from an examination of rocks in the field. In addition, examination of drainage and relief patterns on detailed maps or aerial photographs provides considerable supplementary data on rock structures and distribution.

In the field, the geologist conducts his survey by examining the rock. He looks to see if it is exposed at the surface and not covered by soil or other material. At such exposures, called outcrops, he systematically records the physical characteristics of the rock, thickness of exposure, inclination of the rock, inclination of rock bedding, and development of joints or fractures. In addition, he determines the age of the rock from fossils or the sequence of rock units. Rock investigations are not confined to surface exposures, as the deeper seated rocks are examined by using samples obtained from auger or boreholes. The information gathered by the geologist is placed on a map base by plotting the rock types in color with other data incorporated as symbols or annotations. As an amplification of the map data, more complete descriptions of outcrops are entered in notebooks with the entries keyed to the field map. Surveyors support the geologist by preparing basic topographic maps on which they plot the results of geological investigations and then make such tie measurements to geological features as the geologist may require.

The geologist uses simple survey methods in plotting geological features on a field map. Where an outcrop can be located with reference to a cultural or relief feature, it is generally plotted on a map by spot recognition. In other cases, the relationship of a geological feature to a recognizable topographic feature is established by using a magnetic compass to determine direction and by pacing or taping to measure distance. Slope or small differences in elevation are measured by using a clinometer or hand level, while an altimeter is used where there are large differences in elevation. When the geological survey is keyed to a large-scale plan, the geologist generally uses a plane table and plots data with accuracy commensurate with the accuracy of the base plan.

Base Map Surveys

The survey for the base map should normally take place before the geological survey, because the geologist uses the map in the field to plot his data and to determine his position by identification of topographic details. If aerial photographs are available, the base map need not be made before the geological survey since the geologist can use the aerial photograph as a plotting base and later transfer the data to a base map. However, if possible, the base map should be prepared in advance, even in this case, as the number of aerial photographs needed to cover an area is generally too large to be handled in the field.

Plane table topography is the method best suited to relatively open country. In the absence of detailed instructions, the following specifications are generally satisfactory:

1. BASE DIRECTION. To determine a base direction, take from a known base a side in a triangulation net or a course of a basic control traverse.

2. LOCAL HORIZONTAL CONTROL. Use plane table traverses run in closed circuits or between known control stations of a higher order of accuracy or locate plane table stations by graphical triangulation.

3. LOCAL VERTICAL CONTROL. Where the terrain is relatively level, carry elevation along traverses by vertical angle or stadia-arc measurements, adjusting elevations on closure at a basic control station. For rugged terrain mapped at one of the larger contour intervals, barometric or trigonometric leveling is suitable.

4. SIGHTS. Use telescopic alidade.

5. DISTANCE MEASUREMENTS. Use, in general, stadid or graphical triangulation to locate points and stations. Certain measurements can be made most conveniently by pacing or rough taping.

6. CONTOURING. Locate and determine the elevations of controlling points on summits, in valleys and saddles, and at points of marked change of slope. Interpolate and sketch contours in the field, using these elevations for control.

7. ACCURACY. Distance measurements by stadia should be accurate to 1 part in 500. Side-shot points located by pacing or other rough measurements should be accurate to within 25 feet. Take sights for traverse lines or graphical triangulation with care to obtain the maximum accuracy inherent in the telescopic alidade. The error in the elevation of any point, as read from the finished map, should not exceed one half of the contour interval.

Topography may be located more conveniently in heavily timbered country by stadia measurements from transit-stadia traverse than by the use of the plane table, although the time required for plotting will be increased. The specifications listed above are generally applicable. Read horizontal angles on traverses to 1 minute and horizontal angles for side shots that will be plotted by protractor to the nearest quarter of a degree. Read vertical angles for elevation determination to 1 minute or use the stadia arc. Keep complete and carefully prepared stadia notes and sketches to assure correct plotting.

When the geologist indicates that a map of a lower order of accuracy will fulfill his needs, plane table or compass traverses are suitable.

Use of Aerial Photographs

If aerial photographs are available, the geologist generally uses them instead of a map. The most satisfactory results are obtained from large-scale photographs, 1:15,000 or larger. Some topographic features, such as some ravines, rocky knobs, or sinkholes, are too small to be shown on maps. These features, as well as the larger topographic fares, such as stream channels and swamps, can be observed directly from aerial photographs. The photos also can be used to prepare a base map for portrayal of the field data by tracing planimetric details from an uncontrolled mosaic with spot elevations added from field surveys. The geologist may satisfactorily use contact prints of aerial photographs in place of the base map except where large-scale plans for engineering purposes are to be the base. In such a case the distortion within an aerial photograph does not permit plotting of geological data commensurate with the accuracy of the final plan.

Map Base for Detailed Geological Surveys

Detailed geological surveys generally cover a specific map area geographic region, or specified site from scales of 1:62,500 to 1:600 or larger. In general, the very large scales are used for specific engineering or mineral development problems.

SITE PLANS AND PROPILES.— Geological data affecting foundation designs at construction sites are plotted on plans drawn to scales of 1 inch = 50, 100, 200, or 400 feet. Contour intervals may range from 1 to 10 feet, depending upon the roughness of the terrain Plane table mapping is suited to plotting the topographic features, ranges, and reference points used to locate drill holes, rock outcrops, and other geologic data. When plotting contours on a 1- or 2-foot interval, you should try to locate points that are actually on the contours or to determine elevations at the intersection of closely spaced grid lines staked out on the site. In addition to a plan, the geologist may require that profiles be drawn along selected lines or that the boring logs of test holes be plotted to suitable scales.

USING A TOPOGRAPHIC MAP AS A BASE MAP.— The base map for a detailed geological survey is a complete topographic map or plan with relief expressed by contours. Simple colors and symbolization of basic details are used so that they will not conflict with the overlay of geological information that is shown by colors and symbols. Published topographic maps are used where suitable. The geological survey is expedited if the map base is from a quarter to double the scale of the map on which the information is to be presented. Enlargements of the base map, rather than other maps of a larger scale, are generally used to satisfy these requirements. This permits the direct reduction of geological data to the scale of the final map with a minimum amount of drafting.

When no topographic map is available or if the existing maps are not suitable, a base map or plan must be prepared from detailed topographic surveys. Culture and relief (contours) should be shown in the greatest detail possible. The survey for the base should conform to third-order accuracy where large geographic areas are concerned. Maps made from aerial photographs by precise instrument methods can be used in place of field surveys. Altitude or elevation of the intersection of boreholes and the surface should be accurate to the nearest one-half foot.

PEDOLOGICAL SURVEYS

Sometimes there is a requirement for pedological mapping for the purpose of locating the limits of sand or gravel deposits suitable for concrete aggregates, road materials, or for other construction operations. In such a case, the pedological survey conducted under the direction of the soils engineer and the surveyor's mission would be one of support to the soils engineer's objective.

The engineer's objective in a pedological survey is to prepare data in plan and profile symbolizing soils and outcropping on maps, overlays, and sketches for subsequent engineering uses. The following approaches may be used in conjunction with a soils survey operation:

1. Aerial photography may be used when an extensive area is to be surveyed. Usually no survey measurements are required in this case.

2. Maps of an area that extend several square miles are required when an initial study or technical reconnaissance is needed for an engineering project. Low-order survey measurements usually suffice for the preparation of a reconnaissance sketch upon which the soils engineer can plot the pertinent data.

3. A sketch of an airfield, for example, is frequently required by the soils analyst before construction planning can be initiated. In this case, the surveyor applies low-order measurements to prepare a sketch (1 inch = 100, 200, or 400 feet) upon which the soils engineer plots the results of soil tests and findings.

Aerial Photography

Photo coverage of the area under consideration aids in the establishment of control for the pedological survey. The use of vertical aerial photographs in the planning phase of outlining ground control will speed the survey regardless of the size of the area to be covered If controlled photographs are available, the survey engineer can locate points by pricking or keying them to the photographs. An uncontrolled photograph may be satisfactory for the surveys of low-order accuracy mentioned in the preceding paragraph. According to the soils analyst's instructions, the survey party chief prepares maps or overlays upon which he plots the control and ties them to the pedological features. The pedological interpretation of aerial photographs is the responsibility of the terrain analysts.

Plane Table Traverse

The plane table traverse is best adapted to relatively open country for the preparation of the basic sketch upon which the soils engineer plots pertinent data. In the absence of detailed instructions from the soils engineer, the following procedures are generally satisfactory for preparing a sketch of an area of several square miles (3 miles by 3 miles maximum for initial exploration):

1. SCALE: 1:12,500 or 1:25,000.

2. TRAVERSE CONTROL. Run in circuits or between known positions of a higher order of accuracy.

3. SIGHTING. Use a peep sight or telescopic alidade.

4. DISTANCE MEASUREMENTS. Pace or obtain a rough measurement with tape. When a telescopic alidade is available, use stadia measurements where possible (to reduce the time required for the survey, rather than to increase the accuracy).

5. BASE DIRECTION. To determine a base direction, select known bases: railroad or highway tangents, recognizable features, or reliable topographic maps. In the absence of these known bases, use magnetic north as determined by compass observations.

6. COMPASS. Use military compass, forestry compass, or pocket transit.

7. DISTANCE BETWEEN BASIC CONTROL POINTS. Maintain 3 miles as the extreme maximum distance between stations.

8. ACCURACY. Distances should be measured in such a manner that points can be plotted within 25 feet. For the scales suggested, measurements to 1 part in 100 will suffice. Take sights with peep-sight alidade carefully to maintain directions of an accuracy comparable to distances.

9. TOPOGRAPHY. Topography is usually not required on reconnaissance surveys for pedology, particularly in areas of low relief. Where suitable deposits of sand, gravel, or stone have been located route surveys from the site to the point of use may be required for the location of haulage roads, conveyors, or other means of transporting the material. In hilly terrain, a rough topographic map, obtained by clinometer, pocket transit, or stadia, may be required to make the location of a favorable route easier.

Compass Traverse

In heavily wooded areas, compass traversing is more convenient than plane table traversing; however, more time is required for plotting by the compass traverse method. Traverse lines between stations should be long to reduce the number of observed bearings. Points between stations are located by offsets from the traverse lines. Where local attraction affects compass readings, points are plotted by intersection. Survey readings may be plotted in the field. Notes should be kept in case the traverse must be retraced. In the absence of detailed instructions from the soils engineer, the basic guides for plane table traverse apply.

Field Sheets and Site Plans

The survey engineer must furnish the soils analyst with suitable maps, overlays, and sketches for the plotting of pedological data. After the preparation of a reconnaissance field sheet of an area of several square miles, the soils analyst may require a sketch of a particular site in which many samples are taken for a more detailed study. In the absence of detailed instructions, the surveyor prepares a sketch on a scale of 1 inch = 400 feet and provides ranges and reference points to aid in plotting or tieing in specific positions of auger holes, drill holes, and lines of exposed rock or other pedological features. For plotting the data of a range, cross section, or series of boreholes, the soils analyst may require the surveyor to provide a basic plot on a scale of 1 inch = 100 feet or of 1 inch = 200 feet. Survey measurements will be conducted accordingly.

SOIL SURVEYS

The survey of soil conditions at the site of proposed military construction provides information about the nature, extent, and condition of soil layers; the position of the water table; drainage characteristics; and sources of possible construction materials. The survey of soil conditions is vital to both the planning and execution of military construction operations.

OBJECTIVES OF A SOIL SURVEY

The overall objective of a soil survey is to gather (explore) as much information of engineering significance as possible pertaining to the subsurface conditions in a specified area. Soil samples are collected for laboratory tests to determine if the existing soil conditions could support the type of structure planned for construction without adding other material for stabilization. The exploration is conducted in a specific manner to determine the following information:

1. Location, nature, and classification of soil layers
2. Condition of soils in place (density and moisture content)
3. Drainage characteristics
4. Groundwater and bedrock
5. Development of a soil profile.

Location, Nature and Classification of Soil Layers

Adequate and economic earthwork and foundation design of a structure can be done only when the types and depths of soil are known. By the classification of the soils (discussed later in this chapter), you can predict the extent of problems concerning drainage, frost action, settlement, stability, and similar factors. While you can estimate the soil characteristics by field observations, for laboratory testing, you should obtain samples of the major soil types as well as less extensive deposits that may conversely influence design.

Condition of Natural Soils

The moisture content and density of a soil in its natural state plays an important part in design and construction. The moisture content of a soil in place may be so high as to require the selection of a different site. If the natural soil is sufficiently dense and meets the required specifications, no compaction of subgrade is required. On the other hand, extremely dense soil lying in cut sections maybe difficult to excavate with ordinary tractor-scraper units. Such dense soil often needs to be scarified or rooted before excavation.

Drainage Characteristics

Drainage characteristics, both surface and subsurface, of a soil greatly affect the strength of the soil. This characteristic is controlled by a combination of factors. Some of these factors are void ratio, soil structure and stratification, temperature of soil, depth to water table, and the extent of local disturbance by roots and worms. Coarse-grained soils have better internal drainage than fine-grained soils.

Groundwater and Bedrock

All structures must be constructed at an elevation that ensures they will not be adversely affected by the groundwater table. If a proposed grade line lies below the elevation of the water table, either the grade line must be raised or the water table must be lowered by artificial drainage.

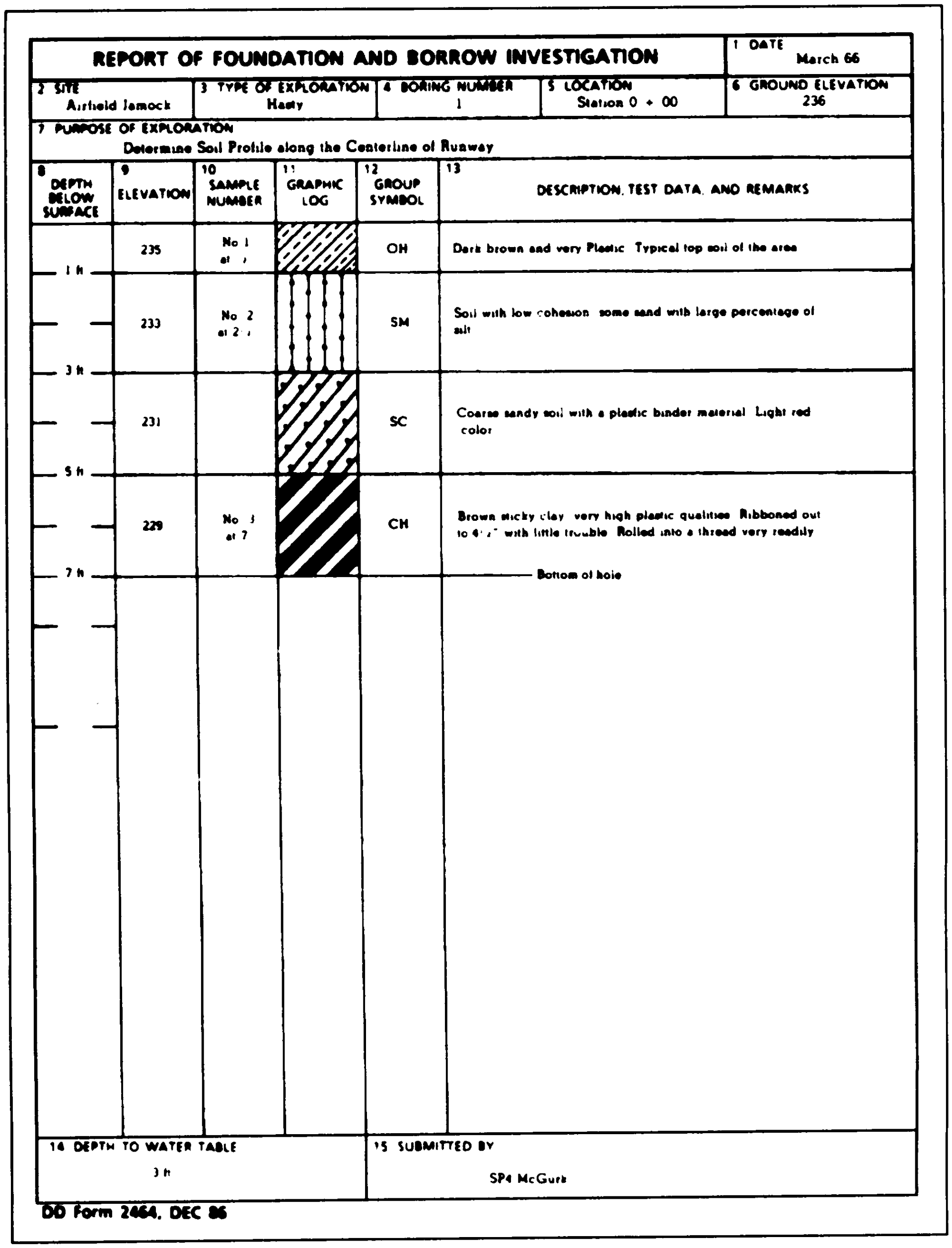
The unexpected discovery of bedrock within the limits of an excavation greatly increases the time and equipment required to excavate. If the amount of rock is extensive, a change in grade or even a change of site may be the only way out.

Field Notes and Soil Profile

The engineer or EA in charge of the soil survey must keep accurate field notes and logs. This person is responsible for surveying, numbering, and recording each boring, test pit, or other exploration investigation.

A log is kept of each test hole. It should show the depth below the surface (or the top and bottom elevations) of each soil layer, the field identification of each soil present at the site, and the number and type of each sample taken. Other items of information you need to include in the log are the density of each soil, changes in moisture content, depth to groundwater, and depth to rock. Keep a detailed field log of each auger boring or test pit made during the soil survey. A typical boring log is shown in figure 16-1.

When you complete the survey, consolidate the information contained in the separate logs. Classify and show the depth of soil layers in each log. It is also helpful for the log keeper to show the natural water contents of fine-grained soils, when possible. Record this along the side of each log. Note the elevation of the groundwater table. This elevation is simply that of any free water standing in the test hole. To permit the water to reach maximum elevation, the engineer or EA should allow 24 hours to elapse before measuring it. This gives a more accurate measurement.



REPORT OF FOUNDATION AND BORROW INVESTIGATION

1 DATE	2 SITE	3 TYPE OF EXPLORATION	4 BORING NUMBER	5 LOCATION	6 GROUND ELEVATION
March 66	Airfield Jamock	Hasty	1	Station 0 + 00	236

7 PURPOSE OF EXPLORATION
Determine Soil Profile along the Centerline of Runway

8 DEPTH BELOW SURFACE	9 ELEVATION	10 SAMPLE NUMBER	11 GRAPHIC LOG	12 GROUP SYMBOL	13 DESCRIPTION, TEST DATA, AND REMARKS
1 ft	235	No 1 at 1		OH	Dark brown and very Plastic Typical top soil of the area
3 ft	233	No 2 at 2		SM	Soil with low cohesion some sand with large percentage of silt
5 ft	231			SC	Coarse sandy soil with a plastic binder material Light red color
7 ft	229	No 3 at 7		CH	Brown sticky clay very high plastic qualities Ribboned out to 4 1/2" with little trouble Rolled into a thread very readily
					Bottom of hole

14 DEPTH TO WATER TABLE	15 SUBMITTED BY
3 ft	SP4 McGurk

DD Form 2464, DEC 86

Figure 16-1.—Typical boring log.

The **soil profile** (fig. 16-2) is a graphical representation of a vertical cross section from the surface downward through the soil layers. It shows the location of test holes and of any ledge rock encountered, a profile of the natural ground to scale, field identification of each soil type, thickness of each soil stratum, profile of the water table, and profile of the finished grade line. Standard soil symbols should be used to indicate the various soil layers. The standard procedure is to add the proper color symbols representing the various soil types you discover.

The soil profile has many practical uses in the location, design, and construction of roads, airfields, dams, and buildings. It greatly influences the location of the finished grade line; these should, of course, be located so as to take full advantage of the best soils available at the site. The profile also shows whether soils to be excavated in the course of construction are suitable for use in embankments or whether you require borrow soils instead. It may show the existence of undesirable soils, such as peat or other highly organic soils; it may also show the existence of bedrock too close to the surface. It aids in planning drainage facilities since these

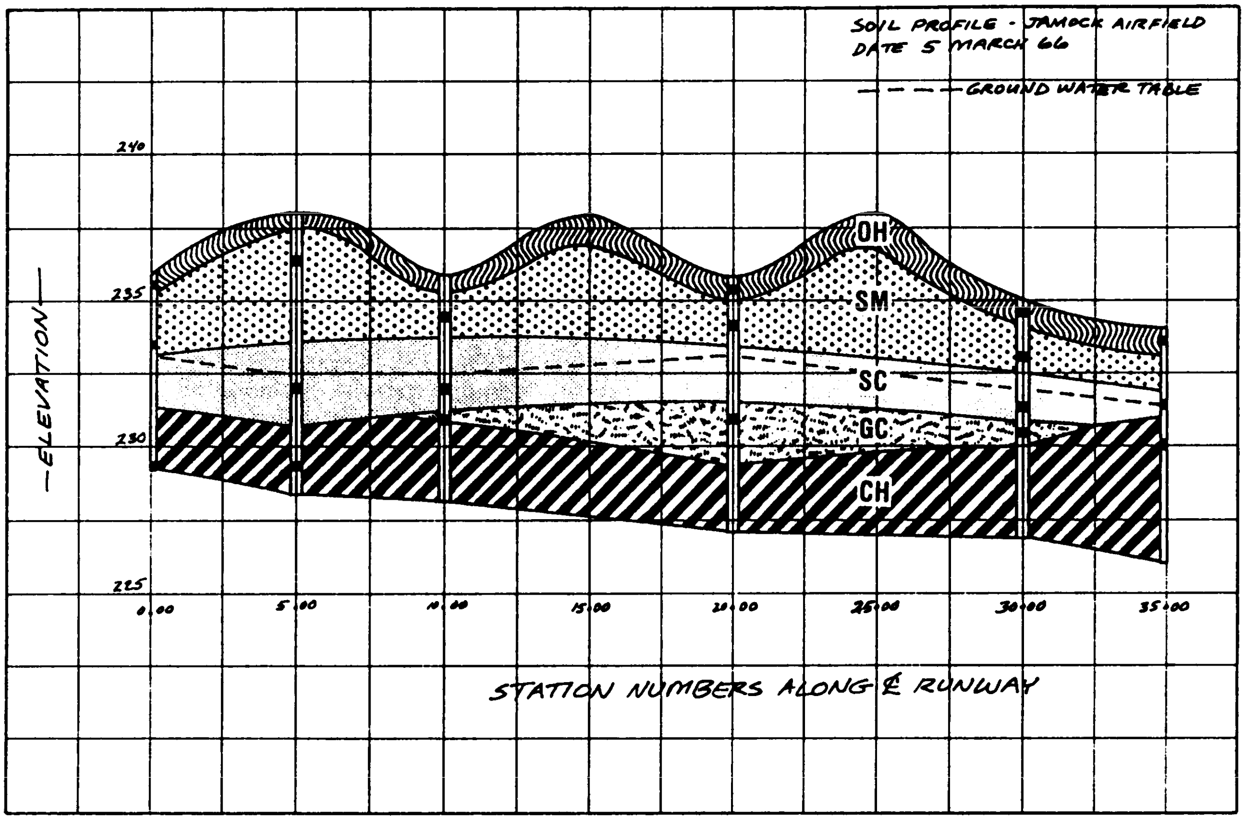


Figure 16-2.—Typical soil profile.

are planned to take advantage of well-draining soils. Considerations relating to frost action become more important when frost-susceptible soils are shown on the profile.

SOURCES OF INFORMATION

Various sources of information are available. Published information and previous soil analyses are sources you may secure without field exploration. Time sources are used mostly to locate, within a large general area, small areas that you may want to investigate further. For final site selection, actual field investigations must be made. Published information sources include engineer intelligence reports, geologic and topographic maps and reports, agricultural soil maps and reports, and air photographs.

Intelligence reports that include maps and studies of soil conditions are usually available for areas in which military operations have been planned. Among the most comprehensive of these are the Terrain Intelligence Folios prepared by the Intelligence Branch of the U.S Army Corps of Engineers, in cooperation with the U.S. Geological Survey.

Geologic maps and brief descriptions of regions or quadrangles are published in the folios of the U.S. Geological Survey. Generally, the smallest rock unit mapped is a formation; geologic maps indicate the extent of formations by means of letter symbols, color, or symbolic patterns. Letter symbols on the map indicate the location of sand and gravel pits; sometimes the back of the map sheet has a brief discussion entitled “Mineral Resources,” that describes the location of construction materials.

Ordinary **topographic maps** may be of some use in estimating soil conditions and can be used in conjunction with geologic maps. Inspection of the drainage pattern (as indicated by contour lines) can provide clues as to the nature of rocks, depth of weathering, soil, and drainage.

Agricultural soils maps and reports are available for many of the developed agricultural areas of the world. These studies are usually concerned primarily with surface soils to a depth of about 6 feet. Information given includes topography, drainage, vegetation, temperature, rainfall, water sources, and rock location. Soils are usually classified according to texture, color, structure, chemical and physical composition, and morphology (topographic features produced by erosion).

The use of **aerial photographs** to show and identify soils is based upon your ability to recognize typical patterns formed under similar conditions. An example might be soil profile and weathering. Principal elements that can be identified on a photograph and that provide a trained observer with clues to the identification of soils are landform, slopes, drainage patterns, erosional characteristics, soil color or "tone," vegetation, and land use.

The form or cofiguration of the land in different types of deposits is definitely characteristic and can be identified on aerial photographs; for example, in desert areas, characteristic dune shapes indicate areas covered by sand subject to movement by wind.

Prevailing ground slopes are clues as to the texture of the soil. Steep slopes are characteristic of granular materials, while relatively flat and smoothly rounded slopes may indicate more plastic soils.

The absence of surface drainage or a very simple drainage pattern often indicates pervious soil. A highly integrated drainage pattern often indicates impervious soils that are plastic and usually lose strength when wet. Drainage patterns tend to reflect underlying rock structure.

The pattern of erosion often provides clues as to the character of the soil. For instance, the cross section or shape of a gully is controlled mainly by the cohesiveness of the soil. Each abrupt change in grade, direction, or cross section indicates a change in the soil profile or rock layers. Short, V-shaped gullies with steep gradients are typical of noncohesive soils; U-shaped gullies with steep gradients indicate deep, uniform silt deposits. Cohesive soils generally develop round, saucer-shaped gullies.

The color of soil is shown on aerial photographs by shades of gray; they range from almost white to almost black. Soft, light colors or tones generally indicate pervious, well-drained soils. Large, flat areas of sand are frequently indicated by uniform, light gray color tones, a flat appearance, and a lack of conformity; this indicates a natural surface drainage. Clays and organic soils frequently appear as dark gray to black areas. In general, a sharp change in color tones represents a change in soil texture.

The character of the vegetation may reflect the surface soil type; however, its significance is often difficult to interpret because of the effects of climate and other factors. To those with local experience, both cultivated and natural vegetation cover are good indicators of soil type.

Knowing the use to which agricultural land is put is often helpful in soil identification. For example, orchards require well-draining soils; therefore, the presence of an orchard implies a sandy soil.

FIELD OBSERVATIONS

Through the use of the various types of published information and aerial photographs, the exploration of a general area maybe narrowed down to several smaller areas suitable for further investigation. The extent and method of collecting more detailed information by field observations depends on the time available.

Rapid ground observation along the proposed highway or airfield location may yield valuable information when conditions do not permit you to make a complete or deliberate soil survey. Observe the soil profile along the natural banks of streams, eroded areas, bomb craters, road cuts, or other places where you see stratified areas. Such observations may indicate types of soil and depths of layers. Scrape off loose surface soils before you examine and make field identification. Samples may be taken from exposed soils for testing in a field laboratory; however, sampling and testing are normally at a minimum in this type of soil survey. Surface soils may be exposed by the use of pick and shovel, particularly in areas of questionable soils or at critical points in the location. Soils identified in the hasty survey may be located by field sketches or on available maps or photographs.

METHODS FOR COLLECTING SAMPLES

A deliberate investigation is made when time and equipment are available and when a more thorough investigation of the subsoil is needed than can be obtained by hasty field observations. The two most commonly used methods of obtaining soil samples for deliberate investigations are **test pits** and **test holes.**

A **test pit** is an open excavation that is large enough for a man to enter and study the soil in its undisturbed condition. This method provides the most satisfactory means for observing the natural condition of the soil and the collection of undisturbed samples. The test pit is usually dug by hand; however, power excavation by dragline, clamshell, bulldozer, backhoe, or a large 24-inch (diameter) power-driven earth auger can expedite the digging-if the equipment is available. Excavations below the groundwater table require the use of pneumatic caissons or the lowering of the water table. Load-bearing tests can also be performed on the soil in the bottom of the pit.

The use of the hand auger is the most common method of digging **test holes.** It is best suited to cohesive soils; however, it can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. By adding a pipe extension, you may use the earth auger to a depth of about 30 feet in relatively soft soils. The sample is completely disturbed but is satisfactory for determining the soil profile, classification, moisture content, compaction capabilities, and similar properties. Auger borings are principally used for work at shallow depths.

Wash boring is probably the most common method used commercially to make deep test holes in all soil deposits except rock or other large obstructions. The test hole is made by a chopping bit fastened to a wash pipe inside a 2-, 4-, or 6-inch (diameter) steel casing. The wash pipe is churned up and down, while the bit, from which water flows under pressure, loosens the soil. The water then carries the soil particles to the surface where they collect inside the casing. An experienced operator can detect from the appearance of the wash water when a change in the type of soil being penetrated has occurred. Wash samples are samples taken directly from the wastewater. They are so disturbed, however, that their value is limited. This method of sampling should not be used if any other means is available.

Dry-sample boring makes use of the wash boring method to sink the hole. When a change of soil type occurs or sometimes at specified depth intervals, the washing is stopped and the bit is replaced by a **sampler.** The sampler (an open-end pipe) is driven into the relatively disturbed soil in the bottom of the hole to extract a sample. The sample is removed and preserved in a sample bottle until tested in the laboratory.

The **undisturbed sampling** process is used to obtain samples with negligible disturbance and deformation for testing for shear strength, compressibility, and permeability. These samples can best be obtained from relatively cohesive soils. Methods that you can use to obtain undisturbed samples are discussed in the EA3 TRAMAN.

The **core boring** process is used to obtain samples from boulders, sound rock frozen ground, and highly resistant soils. The cutting element may consist of diamonds, chilled shot, or steel-tooth cutters. The drill cuts an angular ring in the rock leaving a central core which enters the **core barrel** of the drill and is retained by a holding device when the drill is removed from the hole. This is the best method for determining the characteristic and condition of subsurface rock

PLANNING FIELD EXPLORATIONS

The location of test holes or test pits depends upon the particular situation. Soil tests should be made on samples that are representative of the major soil types in the area. In view of this, the first step in exploration is to develop a general picture of the subgrade conditions to assist in determining the representative soils. Field reconnaissance should be made to study landforms and soil conditions in ditches and cuts. Techniques have been developed whereby aerial photographs can be used for delineating areas of similar soil conditions. Full use should be made of all existing data.

Subgrade Areas

To determine subgrade conditions in an area to be used for road or for airport runway, taxiway, and apron construction, the next step after field reconnaissance is usually to make preliminary borings at strategic points. An arbitrary spacing of these borings at uniform intervals does not give a true picture and is not recommended. Intelligent use of various procedures permit strategic spacing of the preliminary borings to obtain maximum information with a minimum number of borings.

Obtain soil samples for classification purposes in these preliminary borings. After these samples are classified, develop soil profiles. Representative soils should then be selected for detailed testing. Test pits or larger diameter borings should then be made to obtain the samples needed for testing or to permit in-place tests to be made. The types and number of samples required depend on the characteristics of the subgrade soils. Subsoil investigations in areas of proposed pavement must include measurements of in-place water content, density, and strength to determine the depth to which compaction must extend and to ascertain whether soft layers exist in the subsoil.

Borrow Areas

When material is to be borrowed from adjacent areas, make borings carried 2 to 4 feet below the anticipated depth of borrow in these areas. Classify and test samples for water content, density, and strength.

Explore areas within a reasonable haul from the site for possible sources of select material suitable for use as a subbase. Exploration procedures are similar to those described for subgrades. You need test pits or large auger borings drilled with power augers for gravelly materials.

RECOMMENDED PROCEDURES FOR SOIL SURVEYS

The following guide and step-by-step procedures will help the military engineer when conducting soil surveys:

- considerations include soil types, securing of samples, density and moisture content of soil in place, drainage characteristics, and depth to groundwater and bedrock.
- Published information includes geological and topographic reports with maps and agricultural soil bulletins with maps. These require careful interpretation and knowledge of local terms. Aerial photographs used to predict subsurface conditions and previous explorations for nearby construction projects are also useful.
- Field information requires general observation of road cuts, stream banks, eroded slopes, earth cellars, mine shafts, and existing pits and quarries. Test holes may be made with a hand auger or a power auger, if necessary and available. Test pits are necessary where a hand auger cannot penetrate or where large samples are required.
- Local inhabitants, preferably trained observers such as contractors, engineers, and quarry workers, can provide valuable information.

Preparation

Planning of the general layout will determine the extent of the various soil types, vertically and laterally, within the zone where earthwork may occur. Large cuts and fills are the most important areas for detailed exploration.

- Airfield exploration. Place borings at high and low spots, wherever a soil change is expected and in transitions from cut to fall. There is no maximum or minimum spacing requirement between holes; however, the number of holes must be sufficient to give a complete and continuous picture of the soil layers throughout the area of interest. As a general rule, the number of exploration borings required on a flat terrain with uniform soil conditions will be less than in a terrain where the soil conditions change frequently.

Exploration borings should be conducted at the point of interest and located in a manner to get the maximum value for each boring. This may require exploration boring in the centerline as well as edges of runways or roads, but no specific pattern should be employed except as perhaps a staggered or offset pattern to permit the greatest coverage. It is accepted policy to conduct the exploration borings at the edge of existing pavements, unless these pavements have failed completely. In this case, the reason for the failure should be found.

- Depth exploration. Take a cut section 4 feet below subgrade, if possible, and a fill section 4 feet below original ground level, if possible. Effort should be made to locate the groundwater table.

Procedures

- Log the exploration holes or pits.
- Locate and number the samples.
- Determine the elevation and exact location of each hole and tie into the site layout.

Technical Soils Report

A good program for soils testing not only requires that careful and complete tests be performed but also that the tests be completed as quickly as possible and that the data be clearly and accurately presented in a technical soils report. The organization and presentation of the soils report is highly important. The report must be well-organized and must be presented in a logical and concise format with emphasis on technical conclusions. For further discussion and a suggested outline for a soils report, you should refer to *Materials Testing,* NAVFAC MO-330.

SOIL CLASSIFICATION

The principal objective of soil classification is the prediction of engineering properties and behavior of a soil based on a few simple laboratory or field tests. The results of these tests are then used to identify the soil and put it into a group of soils that have similar engineering characteristics. Although there are several different methods of soil classification, the method adopted for use by the military is the **Unified Soil Classification System** (USCS).

Soils seldom exist in nature separately as sand, gravel, or any other single component. Soils usually form mixtures with varying proportions of different size particles. Each component contributes to the characteristics of the mixture. The USCS is based on the textural or plasticity-compressibility characteristics that indicate how a soil will behave as a construction material.

In the USCS, all soils are divided into three major divisions: (1) coarse grained, (2) fine grained, and (3) highly organic. As you know from your previous studies, coarse-grained and fine-grained soils are distinguished by the amount of material that is either retained on or that passes a No. 200 sieve. If 50 percent or more of the soil by weight is retained on a No. 200 sieve, then the soil is coarse-grained. It is fine-grained if more than 50 percent passes the No. 200 sieve. Highly organic soils can generally be identified by visual examination. The major divisions are further subdivided into soil groups. The USCS uses 15 groups and each group is distinguished by a descriptive name and letter symbol, as shown in table AV-1 of appendix V. The letter symbols are derived either from the terms descriptive of the soil fractions, the relative value of the liquid limit (high or low), or the relative gradation of the soil (well graded or poorly graded). The letters that are used in combination to form the 15 soil groups areas follows:

SOIL TYPE	GRADATION	LIQUID LIMIT (LL)
Gravel—G Sand—S Silt—M Clay—C Organic—O Peat—Pt	Well graded—W Poorly graded—P	LL over 50—H LL under 50—L

COARSE-GRAINED SOILS

Coarse-grained soils are divided into two major divisions: gravels and sands. If more than half of the coarse fraction by weight is retained on a No. 4 sieve, the soil is a gravel. It is classed as a sand if more than half of the coarse fraction is smaller than a No. 4 sieve. In general practice there is no clear-cut boundary between gravelly and sandy soils, and as far as behavior is concerned, the exact point of division is relatively unimportant. Where a mixture occurs, the primary name is the predominant fraction and the minor fraction is used as an adjective. For example, a sandy gravel is a mixture containing more gravel than sand by weight.

For the purpose of systematizing the discussion, it is desirable to further divide coarse-grained soils into three groups on the basis of the amount of fines (materials passing a No. 200 sieve) they contain.

GW, GP, SW, and SP Groups

Coarse-grained soils with less than 5-percent nonplastic fines may fall into the groups GW, GP, SW, or SP. The shape of the grain size distribution curve determines the second letter of the symbol.

GW AND SW GROUPS.— The GW groups contain well-graded gravels and gravel-sand mixtures that contain little or no nonplastic fines. The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction or interfere with its free-draining characteristics. The SW groups contain well-graded sands and gravelly sands with little or no plastic fines.

GP AND SP GROUPS.— The GP group includes poorly graded gravels and gravel-sand mixtures containing little or no nonplastic fines. The SP group contains poorly graded sands and gravelly sands with little or no nonplastic fines. These soils will not meet the gradation requirements established for the GW and SW groups.

GM, GC, SM, and SC Groups

Coarse-grained soils containing more than 12-percent fines may fall into the groups designated GM, GC, SM, and SC. The use of the symbols M and C is based upon the plasticity characteristics of the material passing the No. 40 sieve. The liquid limit and

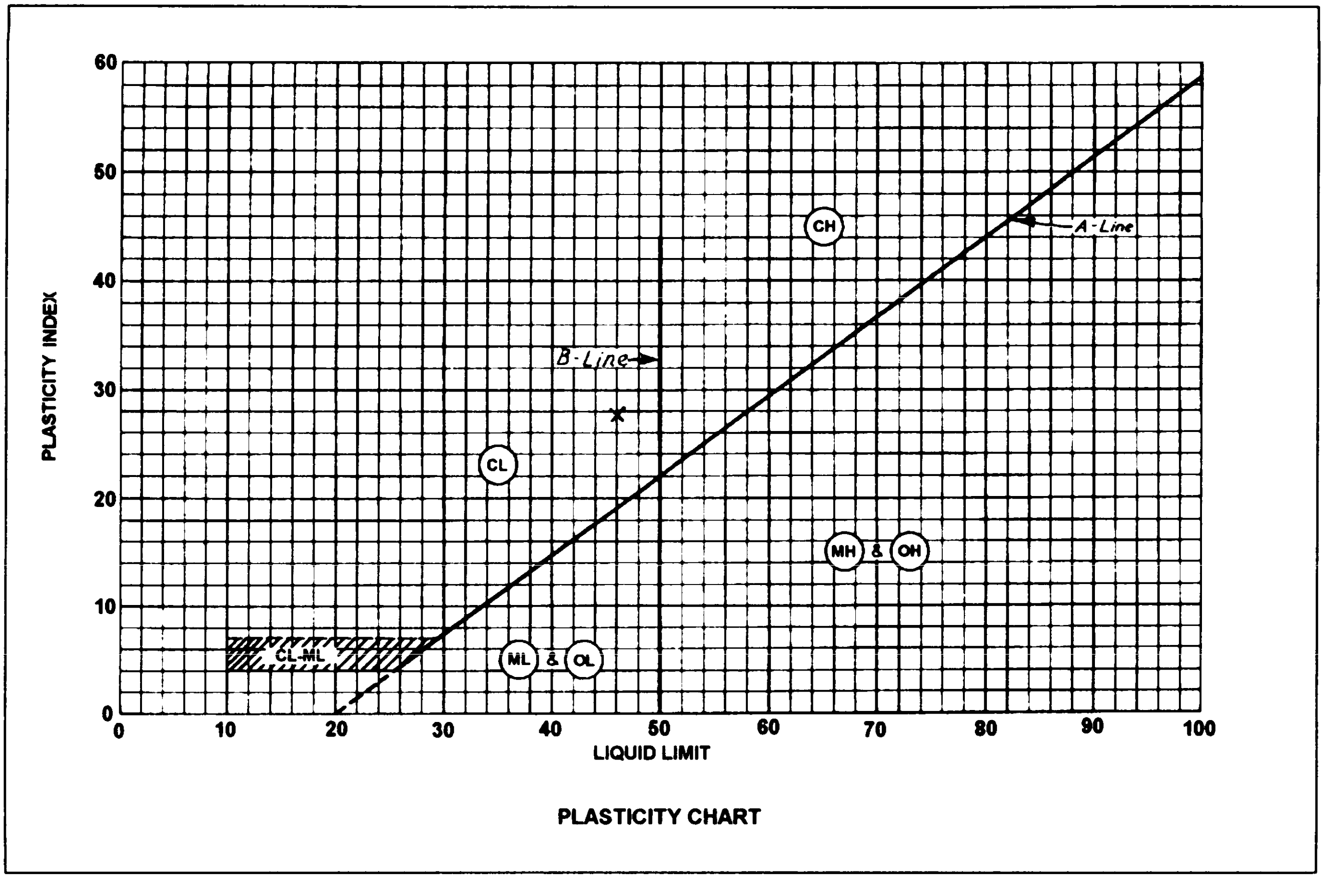


Figure 16-3.-Plasticity chart.

plasticity index are used in specifying the laboratory criteria for these groups. Reference also is made to the plasticity chart shown in figure 16-3 that is based upon established relationships between the liquid limit and plasticity index for many different fine-grained soils. The symbol M is used to indicate that the material passing the No. 40 sieve is silty in character. An M usually designates a fine-grained soil of little or no plasticity. The symbol C is used to indicate that the binder soil is predominately clayey in character.

GM AND SM GROUPS.— Typical of the soils included in the GM group are silty gravels and gravel-sand-silt mixtures. Similarly, the SM group contains silty sands and sand-silt mixtures. For both of these groups, the Atterberg limits must plot below the A-line of the plasticity chart (fig. 16-3). The plasticity index must be less than 4.

GC AND SC GROUPS.— The GC group includes clayey gravels and gravel-sand-clay mixtures. Similarly, SC includes clayey sands and sand-clay mixtures. For both of these groups, the Atterberg limits must plot above the A-line with a plasticity index for more than 7.

Borderline Soils

Coarse-grained soils that contain between 5 and 12 percent of material passing the No. 200 sieve are classed as border line and are given a dual symbol, such as GW-GM. Similarly, coarse-grained soils that contain more than 12 percent of material passing the No. 200 sieve, and for which the limits plot in the shaded portion of the plasticity chart (fig. 16-3), are classed as border line and require dual symbols, such as SM-SC. It is possible in rare instances for a soil to fall into more than one borderline zone. In this case, if appropriate symbols were used for each possible classification, the result would be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated. It is considered best to use only a double symbol in these cases. You should select the two that you believe to be most representative of the probable behavior of the soil. In cases of doubt, the symbols representing the poorer of the possible groupings should be used. For example, a well-graded sandy soil with 8 percent passing the No. 200 sieve, an LL of 28 and a PI of 9 would be designated as SW-SC. If the Atterberg limits of this soil are such as to plot in the shaded portion of the plasticity chart (for example, LL 20 and PI 5), the soil is designated either SW-SC or SW-SM; it depends on the judgment of the engineer from the standpoint of the climatic region in which the soil is located.

FINE-GRAINED SOILS

The fine-grained soils are not classified on the basis of grain size distribution, but according to plasticity and compressibility. Laboratory classification criteria are based on the relationship between the liquid limit and plasticity index as designated in the plasticity chart in figure 16-3. This chart was established by the determination of limits for many soils, together with an analysis of the effect of limits upon physical characteristics.

Examination of the chart shows that there are two major groupings of fine-grained soils. Thase are the L groups, which have liquid limits less than 50, and the H groups, which have liquid limits equal to and greater than 50. The symbols L and H have general meanings of low and high compressibility, respectively. Fine-grained soils are further divided with relation to their position above or below the A-line of the plasticity chart.

ML and MH Groups

Typical soils of the ML and MH groups are inorganic silts. Those of low compressibility are in the ML group. Others are in the MH group. All of these soils plot below the A-line of the plasticity chart. The ML group includes very fine sands, rock flours (rock dust), and silty or clayey fine sand or clayey silts with low plasticity. Loess type soils usually fall into this group. Diatomaceous and micaceous soils usually fall into the MH group but may fall into the ML group when the liquid limit is less than 50. Plastic silts fall into the MH group.

CL and CH Groups

In these groups, the symbol C stands for clay, with L and H denoting low or high liquid limits. These soils plot above the A-line and are principally inorganic clays. In the CL group are included gravelly clays, sandy clays, silty clays, and lean clays. In the CH group are inorganic clays of high plasticity.

OL and OH Groups

The soils in these two groups are characterized by the presence of organic matter; hence the symbol O. All of these soils generally plot below the A-line. Organic silts and organic silt-clays of high plasticity fall into the OL group, while organic clays of high plasticity plot in the OH zone of the plasticity chart. Many of the organic silts, silt-clays, and clays deposited by the rivers along the lower reaches of the Atlantic seaboard have liquid limits above 40 and plot below the A-line. Peaty soils may have liquid limits of several hundred percent and plot well below the A-line because of their high percentage of decomposed vegetational matter. A liquid limit test, however, is not a true indicator in cases in which a considerable portion consists of other than soil matter.

Borderline Soils

Fine-grained soils that have limits that plot in the shaded portion of the plasticity chart are borderline cases and are given dual symbols, such as CL-ML. Several soil types that exhibit low plasticity plot in this general region on the chart where no definite boundary between silty and clayey soils exists.

HIGHLY ORGANIC SOILS

A special classification (Pt) is reserved for the highly organic soils, such as peat, which have characteristics that are undesirable for construction materials and foundations. No laboratory criteria are established for these soils, as they generally can be readily identified in the field by their distinctive color and odor, spongy feel, and fiequently, fibrous textures. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

COEFFICIENT OF UNIFORMITY

In table AV-1 of appendix V, you can see that well-graded gravels (GW) and well-graded sands (SW) must meet certain requirements with regard to C_u and C_c. C_u means the **coefficient of uniformity** with regard to the plotted grain size curve for the material. To see how the coefficient of uniformity is determined, let's consider an example.

Suppose that the sieve analysis of a soil sample identified as FT-P1-1 is as follows:

Sieve	Percent Passing
3/8	100.0
No. 4	85.8
10	74.4
20	51.2
40	30.2
100	16.3
200	3.1

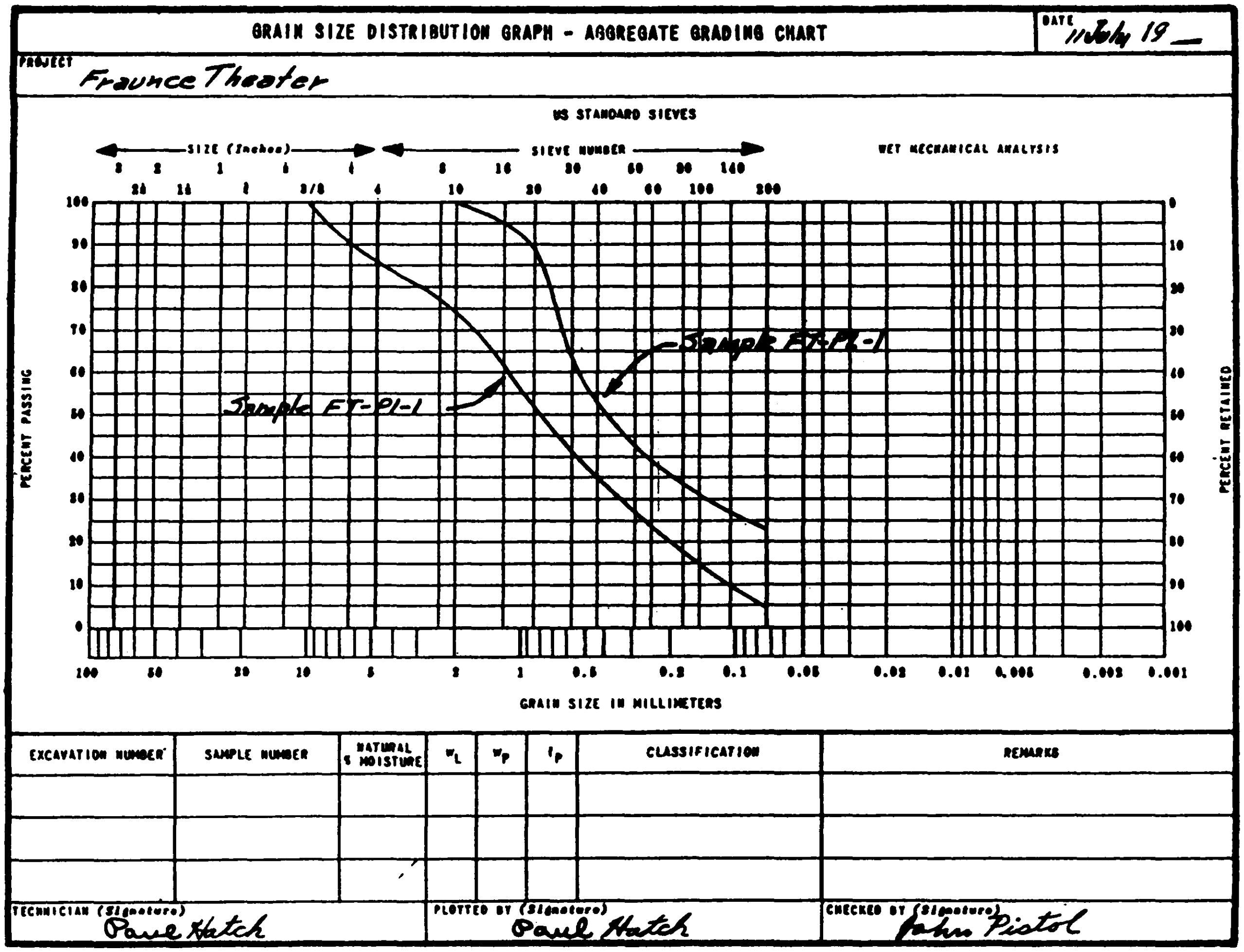


Figure 16-4.—Grain size distribution chart.

You should plot these values on a form like the one shown in figure 16-4. The graph on this form is a logarithm type of layout; coordinates horizontally are sieve sizes (at the top) and grain sizes in millimeters (at the bottom). Vertical coordinates are percents passing.

The formula for determining C_u is as follows:

$$C_u = \frac{D_{60}}{D_{10}}$$

D_{60} means the grain size, in millimeters, indicated by the gradation curve at the 60-percent passing level. In figure 16-4, follow the 60-percent passing line to the point where it intersects the gradation curve for FT-P1-1; then drop down and read the grain size in millimeters indicated below. You read about 1.25mm.

D_{10} means, similarly, the grain size indicated by the gradation curve at the 10-percent passing level. In figure 16-4, this is about 0.11mm.

C_u for this sample, then, is 1.25/0.11, or about 11.4.

COEFFICIENT OF CURVATURE

C_c means the **coefficient of curvature** of the gradation curve. Sometimes the symbol C_g for **coefficient of gradation)** is used instead of C_c. The formula for determining C_c or C_g is as follows:

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

D_{30} is the grain size, in millimeters, indicated by the gradation curve at the 30-percent passing level. In figure 16-4, it is (for FT-P1-1) about 0.35. Therefore, C_c is 0.35^2 divided by (0.11 x 1.25), or about 0.89.

FT-P1-1 is obviously a sand, since more than half of its coarse fraction passes the No. 4 sieve. It is a clean sand, since less than 5 percent of it (see table AV-1, appendix V) passes the No. 200 sieve. However, it is not a well-graded sand (SW), because although its C_u is greater than 6 (prescribed for SW in appendix V), its C_c is less than 1, the minimum prescribed for SW.

Therefore, it is in the SP (poorly graded sands, gravelly sands, little or no fines) category.

SAMPLE CLASSIFICATION PROBLEMS

The following soil classification problems are presented to show you how the soil classification chart (table AV-1, appendix V) is used to classify soils.

Sample Problem 1. From a sieve analysis, a soil shows a C_u of 20 and a C_c of 1.3 and contains 12-percent gravel, 88-percent sand, and no fines (smaller than No. 200). When you are classifying this soil, the first question is whether the soil is coarse-grained or fine-grained. To be Coarse-grained, a soil must have less than 50-percent fines. This soil contains no fines; therefore, it is a coerse-grained soil with the first letter in the symbol either G (gravel) or S (sand). Since it contains more sand (88 percent) than gravel (12 percent), the first letter in the symbol must be S.

The next task is to determine the second letter in the symbol. Since the soil contains no fines, it has no plasticity characteristics; therefore, the second letter of the symbol must be either W (well graded) or P (poorly graded). Since the soil has a C_u greater than 6 and a C_c between 1 and 3, it must be well-graded. Therefore, the symbol for the soil is SW, meaning "well-graded sand."

Sample Problem 2. A sieve analysis shows that a soil contains (50-Percent gravel, 20-percent sand, and 20-percent fines. Plasticity tests show that the portion passing the No. 40 sieve has an LL of 35 and a PI of 8. Since the soil contains less than 50-percent fines, it is a coarse-grained soil. The first letter is therefore either G (gravel) or S (sand). Since gravel predominates over sand, the first letter is G.

The next questions are (1) does the soil contain less than 12-percent fines and (2) is it nonplastic? The answer to both questions is negative, since the sieve analysis shows 20-percent fines, and an LL and PI have been obtained. It follows that the second letter in the symbol must be either C (clay) or M (silt). If you plot LL 35 and PI 8 on the plasticity chart (fig. 16-3), you will find that the plotted point lies below the A-line. Therefore, the complete symbol is GM, meaning "silty gravel."

Sample Problem 3. A sieve analysis shows that a soil contains 10-percent sand and 75-percent fines. Plasticity tests show that the portion passing the No. 40 sieve has an LL of 40 and a PI of 20. Since the soil contains more than 50-percent fines, it is a fine-grained soil; therefore, the first letter in the symbol is either O (organic), M (silt), or C (clay). Assume that the soil shows no indication of being organic (principal indications are black color and musty odor); it follows that the first letter must be either M or C.

If you plot an LL of 40 and a PI of 20 on the plasticity chart, you find that the plotted point lies above the A-line; therefore, the first letter in the symbol is C. Since the liquid limit is less than 50 (which brings the plotted point to the left of the B-line), the second letter of the symbol is L (low plasticity or compressibility). The complete symbol is CL, meaning "clay with low compressibility."

FIELD IDENTIFICATION

Sometimes the lack of time and facilities makes laboratory soil testing impossible in military construction. Even when laboratory tests are to follow, field identification tests must be made during the soil exploration. Soil types need to be identified so that duplicate samples for laboratory testing are held to a minimum. Several simple tests used in field identification are described in this section. Each test may be performed with a minimum of time and equipment. However, the classification derived from these tests should be considered an approximation. The number of tests used depends on the type of soil and the experience of the individual using them. Experience is the greatest asset in field identification; learning the technique from an experienced technician is the best method of acquiring the skill. If assistance is not available, you can gain experience by getting the "feel" of the soil during laboratory testing. An approximate identification can be made by spreading a dry sample on a flat surface and examining it. All lumps should be pulverized until individual grains are exposed but not broken; breaking changes the grain size and the character of the soil. A rubber-faced or wooden pestle are recommended. For an approximate identification, however, you can mash a sample underfoot on a smooth surface.

Field tests may be performed with little or no equipment other than a small amount of water. However, accuracy and uniformity of results is greatly increased by the proper use of certain items of equipment. For testing purposes, the following equipment or accessories may be used:

- SIEVES. A No. 40 U.S. standard sieve is perhaps the most useful item of equipment. Any screen with about 40 openings per lineal inch could be used. An approximate separation may be made by sorting the materials by hand. Generally, No. 4 and No. 200 sieves are used for separating gravel, sand, and fines.

- PIONEER TOOLS. Use a pick and shovel or a set of entrenching tools for collecting samples. A hand auger is useful if samples are desired from depths of more than a few feet below the surface.

- STIRRER. The spoon issued as part of the mess equipment serves in mixing materials with water to the desired consistency. It also can aid in collecting samples.

- KNIFE. Use a combat knife or pocketknife for collecting samples and trimming them to the desired size.

- MIXING BOWL. Use a small bowl with a rubber-faced pestle to pulverize the fine-grained portion of the soil. Both may be improvised. You could use a canteen cup and wood pestle.

- PAPER. Several sheets of heavy paper are needed for rolling samples.

- PAN AND HEATING ELEMENT. Use a pan and heating element to dry samples.

- SCALES. Use balances or scales to weigh samples.

The Unified Soil Classification System, as shown in appendix V, considers three soil properties: (1) percentage of gravel, sand, or fines, (2) shape of the grain size distribution curve, and (3) plasticity. Other observed properties should also be included in the soil description, whether made in the field or in the laboratory.

The following descriptions represent some of the typical characteristics used in describing soil:

- Dark brown to white or any suitable color shade description

- Coarse-grained, maximum particle size 2 3/4 inches, estimated 60-percent gravel, 36-percent sand, and 4-percent fines (passing through No. 200 sieve)

- Poorly graded (gap-graded, insufficient fine gravel)

- Gravel particles subrounded to rounded, or predominately gravel

- Nonplastic

- Mostly sand with a small amount of nonplastic fines (silt)

- Slightly calcareous, no dry strength, dense in the undisturbed state

VISUAL EXAMINATION

Visual examination should establish the color, grain size, grain shapes (of the coarse-grained portion), some idea of the gradation, and some properties of the undisturbed soil.

Color is often helpful in distinguishing between soil types, and with experience, one may find it useful in identifying the particular soil type. Color may also indicate the presence of certain chemicals. Color often varies with moisture content of a soil. For this reason, the moisture content at the time of color identification should be included. Some of the more familiar color properties are listed below.

- Generally, colors become darker as the moisture content increases and lighter as the soil dries.

- Some fine-grained soils (OL, OH) with dark drab shades of brown or gray, including almost black, contain organic colloidal matter.

- In contrast, clean, bright looking shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils.

- Gray-blue or gray- and yellow-mottled colors frequently result from poor drainage.

- Red, yellow, and yellowish brown result from the presence of iron oxides.

- White to pink may indicate considerable silica, calcium carbonate, or aluminum compounds.

The maximum particle size of each sample considered should always be estimated if not measured. This establishes the upper limit of the gradation curve. Gravels range down to the size of peas. Sands start just below this size and decrease until the individual grains can barely be seen by the naked eye. The eye can normally see individual grains about 0.05mm in size or about the size of the No. 200 screen. Thus silt and clay particles (which are smaller than this dimension) are not detected as individual grains.

While the sample for grain sizes is being examined, the shapes of the visible particles can be determined. Sharp edges and flat surfaces indicate an angular shape; smooth, curved surfaces are associated with a rounded shape. Particles may not be completely angular or completely rounded. These particles are called subangular or subaounded, depending on which shape predominates.

Laboratory analysis must be performed when accurate grain size distribution is to be determined. However, you can approximate the distribution by visual examination using the following steps:

1. Separate the larger grain particles from the rest of the soil sample by picking them out one at a time.

2. Examine the remainder of the soil and estimate the proportion of visible individual particles (larger than the No. 200 sieve) and the fines.

3. Convert these estimates into percentages by weight of the total sample. If the fines exceed 50 percent, the soil is considered fine-grained (M, C, or O); if the coarse material exceeds 50 percent, the soil is coarse-grained (G or S).

4. Examine the coarse-grained soil for gradation of particle sizes from the largest to the smallest. A good distribution of all sizes without too much or too little of any one size means the soil is well-graded (W). Overabundance or lack of any size means the material is poorly graded (P).

5. Estimate the percentage of the fine-grained portion of the coarse-grained soil. If nonplastic fines are less than 5 percent of the total, the soil maybe classified either as a GW, GP, SW, or SP type, depending on the other information noted above.

6. If the fine-grained portion (Step 5 above) exceeds 12 percent, the soil is either silty (M) or clayey (C) and requires further testing to identify.

7. Fine-grained portions (Step 5 above) between 5- and 12-percent (nonplastic fines or fines not interfering with drainage, or 0 to 12 percent plastic fines) total are border line and require a double symbol (GW-GM or SW-SM).

8. Fine-grained soils (M, C, or O) from Step 3 above require other tests to distinguish them further. Grain size distribution of fine portions is normally not performed in field identification. However, should it become necessary, you can approximate the grain size of the fines by shaking them in a jar of water and allowing the material to settle. The materials settle in layers of different sizes from which the proportion can be estimated. It should be kept in mind that gravel and sand settle into a much denser mass than either clay or silt.

If you use the characteristics determined up to this point, it is possible to evaluate the soil as it appeared in place (undisturbed). Gravels or sands can be described qualitatively as loose, medium, or dense. Clays maybe hard, stiff, or soft. The ease or difficulty with which the sample was removed from the ground is a good indicator. Soils that have been cultivated or farmed can be further evaluated as loose and compressible. Highly organic soils can be spongy and elastic. In addition, moisture content of the soil influences the in-place characteristics. This condition should be recognized and reported with the undisturbed soil properties.

BREAKING OR DRY-STRENGTH TEST

The breaking test is done only on the material passing the No. 40 sieve. This test as well as the roll test and the ribbon test, is used to measure the cohesive and plastic characteristics of the soil. The test normally is made on a small pat of soil about 1/2 inch thick and about 1 1/2 inches in diameter. The pat is prepared by molding a portion of the soil in the wet plastic state into the size and shape desired and then allowing the pat to dry completely. Samples may be tested for dry strength in their natural condition as they are found in the field However, you should not depend too much on such tests because of the variations that exist in the drying environment under field conditions. You may approximate the dry strength by such a test however, and verify it later by a carefully prepared sample.

After the prepared sample is thoroughly dry, attempt to break it using the thumbs and forefingers of both hands (fig. 16-5). If you are able to break it, then try to powder it by rubbing it with the thumb and fingers of one hand.

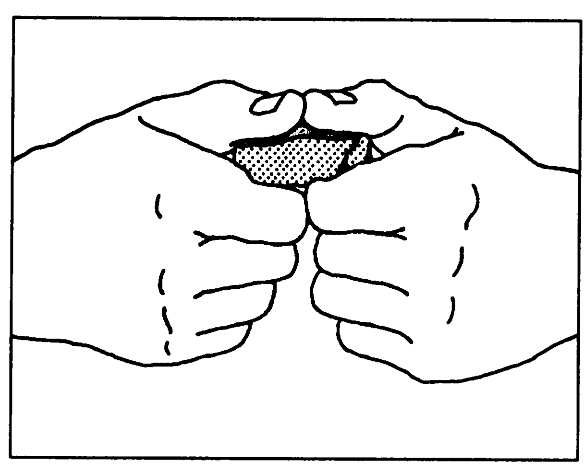


Figure 16-5.-Breaking or dry-strength test.

The typical reactions that are obtained in this test for various types of soils are described below.

1. Very highly plastic soils (CH). The pat cannot be broken or powdered by finger pressure.

2. Highly plastic soils (CH). The pat can be broken with great effort, but cannot be powdered.

3. Medium plastic soils (CL). The pat can be broken and powdered with some effort.

4. Slightly plastic soils (ML, MH, or CL). The pat can be broken quite easily and powdered readily.

5. Nonplastic soils (ML, MH, OL, or OH). The pat has little or no dry strength and crumbles or powders when picked up.

ROLL OR THREAD TEST

This test is performed only on the material passing a No. 40 sieve. First, you mix a representative portion of the sample with water until it can be molded or shaped without sticking to your fingers. This moisture content is referred to as being just below the sticky limit.

Next, prepare a nonabsorbent rolling surface by placing a sheet of glass or heavy wax paper on a flat or level support. Place the sample on this surface and shape it into an elongated cylindrical shape. Then attempt to roll the cylindrical sample rapidly into a thread approximately 1/8 inch in diameter (fig. 16-6). If the moist soil rolls into a thread, it has some plasticity. The number of times it can be rolled into a thread without crumbling is a measure of the degree of plasticity of the soil. Materials that cannot be rolled in this manner are nonplastic or have extremely low plasticity.

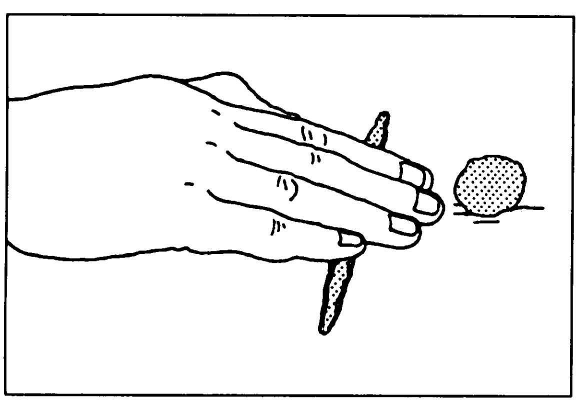


Figure 16-6.-Roll or thread test.

The results of this test indicate the following:

1. High plasticity (CH). The soil can be molded into a ball or cylinder and deformed under firm finger pressure without crumbling or cracking.

2. Medium plasticity (CL). The soil can be molded, but it cracks or crumbles under finger pressure.

3. Low plasticity (CL, ML, or MH). The soil cannot be lumped into a ball or cylinder without breaking up.

4. Organic material (OL or OH). The soil forms a soft, spongy ball or thread when molded.

5. Nonplastic soil (ML or MH). The soil cannot be rolled into a thread at any moisture content.

From the thread test, the cohesiveness of the material near the plastic limit may also be described as weak, firm, or tough. The higher the soil is on the plasticity chart, the stiffer the threads are as they dry out and the tougher the lumps are if the soil is remolded after rolling.

RIBBON TEST

The ribbon test is performed only on the material passing the No. 40 sieve. The sample prepared for use in this test should have a moisture content that is slightly below the sticky limit. Using this material, form a roll of soil about 1/2 to 3/4 inch in diameter and about 3 to 5 inches long. Place this material in the palm of your hand and, starting at one end, flatten the roll, forming a ribbon 1/8 to 1/4 inch thick. This is done by squeezing it between your thumb and forefinger (fig. 16-7). Handle the sample carefully to form the maximum length of ribbon that can be supported by the cohesive properties of the material. If the soil sample holds together for a length of 6 to 10 inches without breaking, the material is then considered to be both highly plastic and highly compressive (CH). If the soil cannot be ribboned, it is nonplastic (ML or MH). If it can be ribboned, it is nonplastic (ML or MH). If it can be ribboned only with difficulty into short lengths, the soil is considered to have low plasticity (CL). The roll test and the ribbon test complement each other in giving a clearer picture of the degree of plasticity of soil.

WET-SHAKING TEST

The wet-shaking test is performed only on the material passing the No. 40 sieve. In the preparation of a portion of the sample for use in this test, enough material to form a ball of material about 3/4 inch in

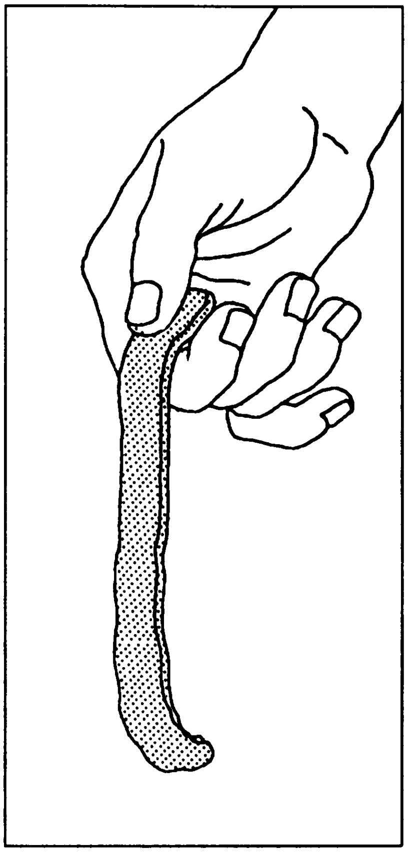


Figure 16-7.-Ribbon test.

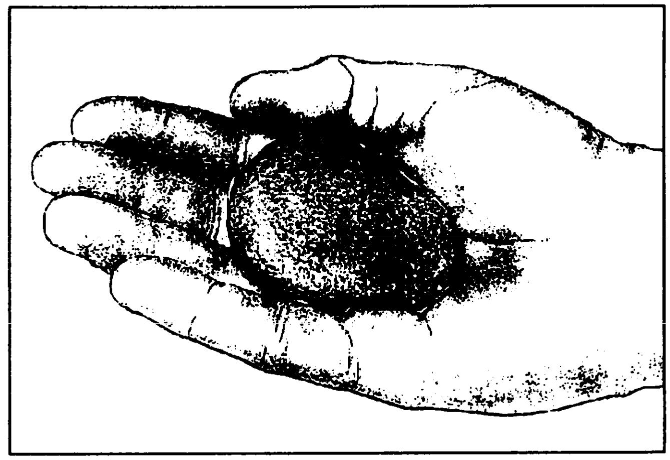


Figure 16-8.-Livery appearance produced by wet-shaking test.

diameter is moistened with water. This sample should be just wet enough that the soil does not stick to your fingers upon remolding or just below the sticky limit.

For testing, the sample is then placed in the palm of the hand and shaken vigorously. This is usually done by jarring the hand on the table or some other firm object or by jarring it against the other hand. The soil is said to have given a reaction to this test if, when it is shaken, water comes to the surface of the sample producing a smooth, shiny appearance. This appearance is frequently described as livery (fig. 16-8).

The sample is then squeezed between the thumb and forefinger of the other hand. As this is done, the surface water quickly disappears and the surface becomes dull. The sample becomes firm, resisting deformation, and cracks occur as pressure is continued. Finally the sample crumbles like a brittle material.

The vibration caused by shaking the soil sample tends to reorient the soil grains, decrease the voids, and force water, which had been within these voids, to the surface. Pressing the sample between the fingers tends to disarrange the soil grains and increase the void spaces. The water is then drawn into the soil. If the water content is still adequate, shaking the broken pieces causes them to liquefy again and flow together, and the complete cycle may be repeated. This process can occur only when the solid grains are bulky in shape and noncohesive in character. Very fine sands and silts fall into this category and are readily identified by the wet-shaking test. Since it is rare that fine sands and silts occur without some amount of clay mixed with them, there are varying degrees of reaction to this test. Even a small amount of clay tends to retard this reaction greatly. Some of the descriptive terms applied to the different rates of reaction to this test are as follows:

- SUDDEN OR RAPID. A rapid reaction to the shaking test is typical of nonplastic, fine sands and silts. A material known as rock flour that falls into the silt-size ranges also gives this type of reaction.

- SLUGGISH OR SLOW. A sluggish reaction indicates slight plasticity such as might be found from a test of some organic or inorganic silts or silts containing a small amount of clay. Even a slight content of colloidal clay imparts some plasticity and materially slows up the reaction to the shaking test. Extremely slow or no reaction is typical of all inorganic clays and of the highly plastic organic clays.

- NO REACTION. Obtaining no reaction at all to this test does not indicate a complete absence of silt or fine sand.

ODOR TEST

Organic soils of the OL and OH groups usually have a distinctive, musty, slightly offensive odor. With experience, you can use this odor as an aid in identifying these groups. This odor is especially apparent from fresh samples. The odor gradually reduces when exposed to air but can again become effective when you heat a wet sample. Organic soils are undesirable as foundation or base course material. They are usually removed from the construction site and wasted.

BITE OR GRIT TEST

The bite or grit test is a quick and useful method that is used to identify sand silt, or clay. In this test, a small pinch of solid material is ground lightly between the teeth. The soils are identified as follows:

- SANDY SOILS. The sharp, hard particles of sand grate harshly between your teeth and are highly objectionable. This is true even of the fine sand.

- SILTY SOILS. The silt grains are so much smaller than sand grains that they do not feel nearly so harsh between your teeth. They are not particularly gritty although their presence is still easily detected.

- CLAYEY SOILS. The clay grains are not at all gritty, but feel smooth and powdery like flour between the teeth. Dry lumps of clayey soils stick when lightly touched with your tongue.

SLAKING TEST

The slaking test is used to assist in determining the quality of certain soil shales and other soft rocklike materials. To perform this test, place the soil in the sun or in an oven to dry. Then allow it to soak in water for at least 24 hours. After this, examine the strength of the soil. Certain types of shale disintegrate completely and lose all strength.

ACID TEST

The acid test is used to determine the presence of calcium carbonate. It is performed by placing a few drops of hydrochloric acid on a piece of soil. A fizzing reaction (effervescence) to this test indicates the presence of calcium carbonate. The degree of reaction gives an indication of the concentration. Calcium carbonate normally is desirable in a soil because of the cementing action it adds to the stability. (Some very dry noncalcareous soils appear to effervesce after they absorb the acid. This effect can be eliminated in all dry soils by moistening the soil before applying the acid.) This cementing action normally develops only after a long curing period and cannot be counted upon for strength in most military construction. The primary use for this test is to give abetter value of fine-grained soils that you have tested in place.

SHINE TEST

The shine test is another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay has a definite shine when rubbed with a fingernail, a pocketknife blade, or any smooth metal surface. On the other hand, a piece of lean clay does not display any shine, but remains dull.

FEEL TEST

The feel test is a general-purpose test that requires experience and practice before reliable results can be obtained. Two characteristics you can determine by the feel test are consistency and texture.

The natural moisture content of a soil is of value as an indicator of the drainage characteristics, nearness to the water table, or other factors that may affect this property. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. The consistency is described by such terms as hard, stiff, brittle, friable, sticky, plastic, or soft. Remold the soil by working it in your hands. Observe changes, if any. You can use the feel test to estimate the natural water content relative to the liquid or plastic limit of the soil. Clays that turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff and crumbles upon being remolded, the natural water content is below the plastic limit.

The term texture, as applied to the fine-grained portion of a soil, refers to the degree of fineness and uniformity. The texture is described by such expressions as floury, smooth, gritty, or sharp, depending upon the sensation produced by rubbing the soil between the fingers. Sensitivity to this sensation may be increased by rubbing some of the material on a tender skin area such as the wrist. Fine sand feels gritty. Typical dry silts will dust readily and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

QUESTIONS

Q1. The purpose of a geological survey is to take which of the following actions?

1. *Locate rock formations in the field and determine their physical characteristics*
2. *Determine rock age and distribution*
3. *Determine types of rock and their mineral content*
4. *All of the above*

Original sample weight: 2,459 grams		
Sieve size	Weight of sieve	Weight of sieve and sample
1/2	210	210
1/4	230	624
No. 4	205	332
No. 8	225	691
No. 20	215	612
No. 60	235	581
No. 100	250	612
No. 200	260	515

Figure 16-9.—Sieve analysis data.

Q2. *Is it true or false that surveys made in support of pedology concern the locations of the limits of sand or gravel deposits suitable for use as construction materials?*

Q3. *Structures must be constructed at an elevation that will ensure that they will not be adversely affected by the groundwater table. If the proposed grade line lies below the elevation of the groundwater line, you may have to*

1. *change the location*
2. *lower the groundwater table by means of artificial drainage systems*
3. *raise the proposed grade*
4. *do either 2 or 3 above, depending upon land characteristics*

Q4. *From the sieve analysis data shown in figure 16-9, determine and plot the grain size distribution using figure 16-10. For this soil*

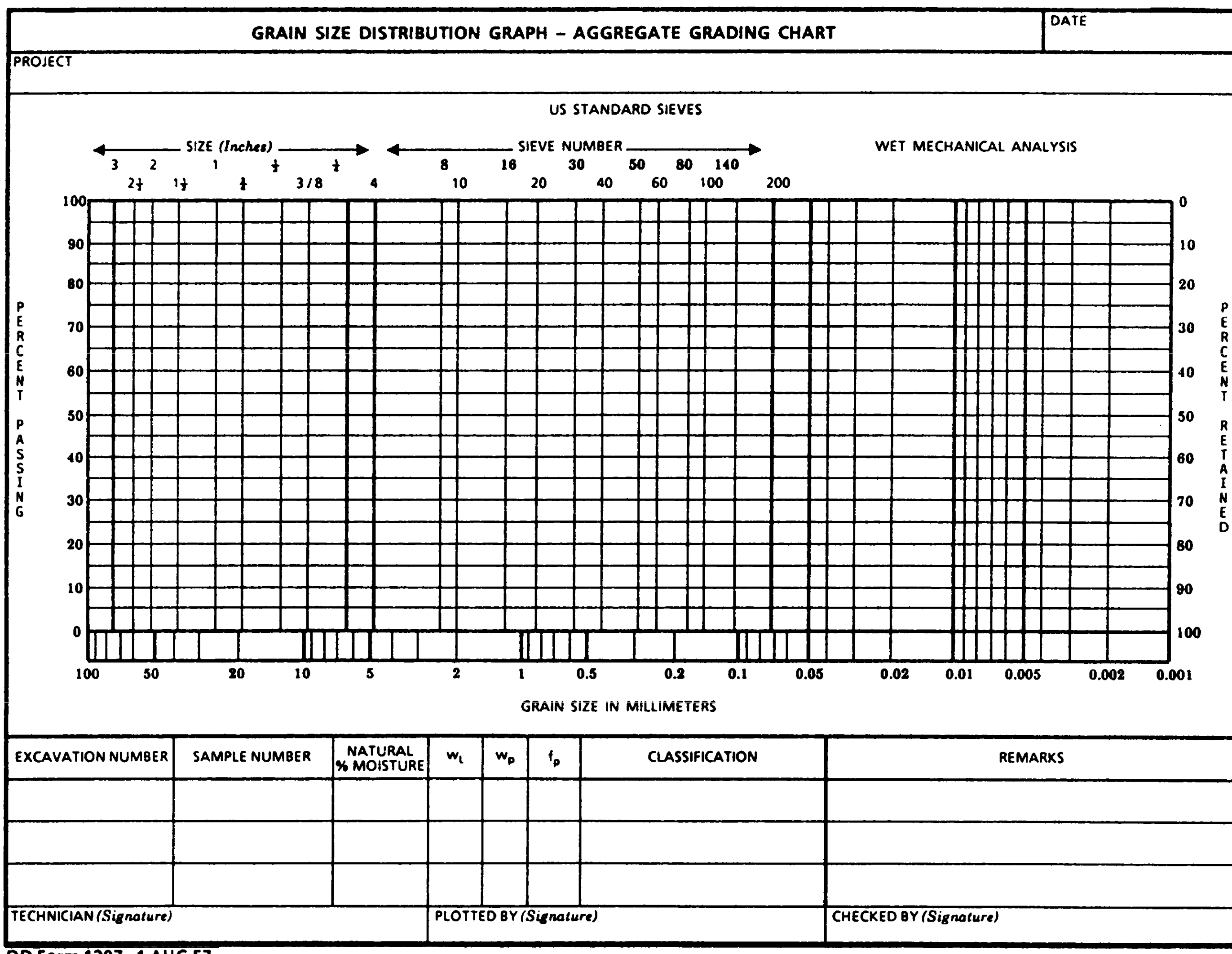


Figure 16-10.—Grain size distribution graph.

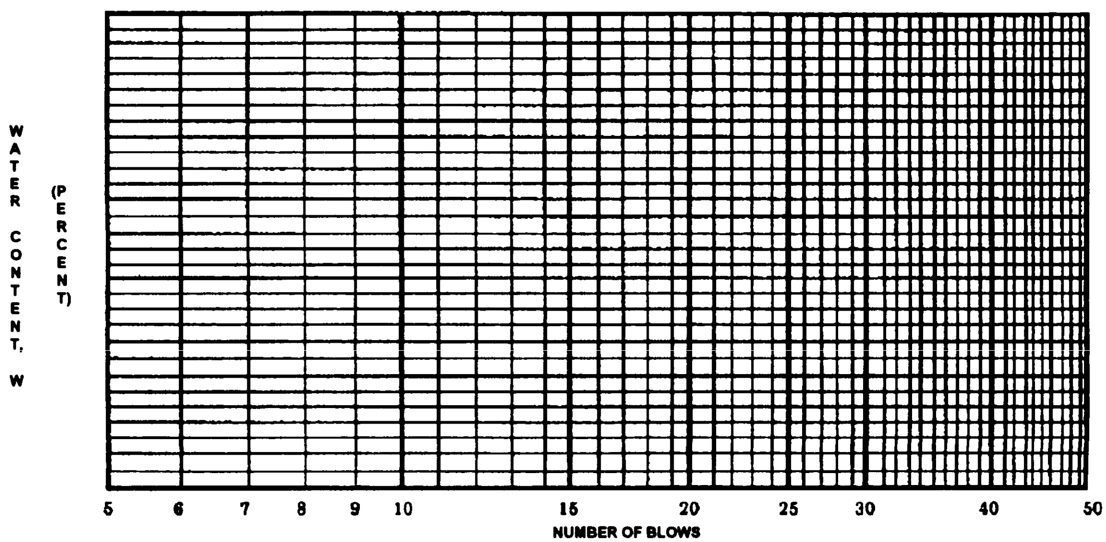
ATTERBUERG LIMITS DETERMINATION

PROJECT	EXCAVATION NUMBER	SAMPLE NUMBER
DATE		

LIQUID LIMIT, W_L

RUN NUMBER	1	2	3	4		
TARE NUMBER						
A. WEIGHT OF WET SOIL + TARE	43.61	43.78	43.07	44.89		
B. WEIGHT OF DRY SOIL + TARE	40.07	40.62	39.96	41.27		
C. WEIGHT OF WATER, W_W						
D. WEIGHT OF TARE	33.12	33.29	32.36	32.13		
E. WEIGHT OF DRY SOIL, W_s						
WATER CONTENT, W =						
NUMBER OF BLOWS	15-17-16	23-24-25	29-28-30	33-33		

W_L LL=	W_P PL=	IP PI =



PLASTIC LIMIT, W_P

RUN NUMBER	1	2	3		NATURAL WATER CONTENT
TARE NUMBER					
P. WEIGHT OF WET SOIL + TARE	55.36	54.75	60.30		
G. WEIGHT OF DRY SOIL + TARE	54.93	54.23	59.87		
H. WEIGHT OF WATER, W_W					
I. WEIGHT OF TARE	53.13	52.64	57.49		
J. WEIGHT OF DRY SOIL, W_s					
WATER CONTENT, W =					
PLASTIC LIMIT, I_P *(Average w)*					

REMARKS

TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*

DD Form 1209, AUG 57

Figure 16-11.—Atterberg limits determination.

sample, what is the (a) percentage of gravel, (b) percentage of sand, (c)percentage of fines, and (d) the USCS classification?

Q5. For a certain soil sample, assume that 60 percent of the material passes the No. 200 sieve, that there is no indication that the material contains organic matter and that Atterberg limits testing has been performed Figure 16-11 is the partially completed record entries for the Atterberg limits determination. Based on this information and using the plasticity chart shown in figure 16-3, what is the (a) liquid limit, (b) plasticity index, and (c) USCS classification of the soil sample?

Q6. Which of the following field tests can be used to approximate the cohesive and plastic characteristics of a soil sample?

1. *Dry strength*
2. *Ribbon*
3. *Roll*
4. *Each of the above*